N79-72777
(NASA-CR-106920) THE USE OF INTELSAT SATELLITES FOR DIRECT VOICE AND DATA COMMUNICATIONS WITH MANNED SPACE VEHICLES (Bellcomm, Inc.) 36 p
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FACILITY FORM 602
X70-10323
(ACCESSION NUMBER) (THRU)
86
(PAGES)
2-C
(CODE)
07
(NASA CR OR TMX OR AD NUMBER) (CATEGORY)

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X70-10323

COVER SHEET FOR TECHNICAL MEMORANDUM

TITLE- The Use of Intelsat Satellites for Direct Voice and Data Communications with Manned Space Vehicles

TM- 69-2034-2

DATE- March 31, 1969

FILING CASE NO(S)- Case 900

AUTHOR(S)- R. K. Chen

FILING SUBJECT(S)- (ASSIGNED BY AUTHOR(S)- Intelsat Satellites
Direct Communications Relay between Space Vehicle and MCC

Available from NASA to U. S. Government agencies [redacted], [redacted] only.

ABSTRACT

The practicability of using Intelsat satellites for direct voice communications relay between an orbiting manned spacecraft and a ground station was examined in a prior memorandum. The cost model used indicated that when sufficient channels are purchased on Intelsat satellites, there is excess capacity in the purchased channels which could be used for relaying data. An analysis is presented of the use of the excess capability that exists when sufficient satellite capacity is purchased to support a single two-way voice channel between an earth orbiting manned spacecraft and earth. This excess must be purchased because (1) the minimum service sold by Intelsat is equivalent to 24 voice channels (a bandwidth of 5MHz) and (2) present communications satellites are designed to provide their stated capacities, in terms of equivalent voice channels, only when operating with large, standardized ground stations with receive gain to noise temperature ratios of 40.7dB or higher. Any station with less capability must pay for the increased percentage of the satellite used.

At present, Intelsat II satellites are used for Apollo missions to provide real time communications between the continental United States and selected land and ship stations of the MSFN. The service now provides six (6) two-way voice/data grade circuits plus two (2) teletype circuits between each station and the U. S. In terms of real time information flow between the Apollo spacecraft and the mission control center (MCC), the present service provides the capability for voice and 1.0 kbps up-data on the up-link, simultaneously with voice and 10 kbps telemetry on the down-link for an equivalent real time coverage

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ABSTRACT (Cont'd)

of less than 20%. In contrast, it is concluded that, by using Intelsat IV satellites for direct relay service between the orbiting manned spacecraft and a ground station in the United States, the cost of obtaining continuous coverage with voice and 3.9 kbps up-data on the up-link simultaneously with voice and 160 kbps telemetry on the down-link would be approximately one fourth (1/4) of the current cost of the present Intelsat II service. In order to obtain this direct relay service, the manned spacecraft would need a properly equipped terminal; its major characteristics would typically be an eleven-foot diamter antenna and a 100 watt transmitter using digital modulation techniques and a time division multiplex system.

BELLCOMM, INC.

SUBJECT: The Use of Intelsat Satellites for Direct Voice and Data Communications With Manned Space Vehicles Case 900

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FROM: R. K. Chen

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TECHNICAL MEMORANDUM

I. INTRODUCTION

The practicability of using present and anticipated Intelsat satellites for direct voice communications relay between an orbiting manned spacecraft and a ground station for the post-Apollo period was examined in a prior report.(1) It was concluded that a single two-way voice channel could be provided with reasonable modifications and additions to the manned spacecraft. From the cost model used in Reference 1, it was also concluded that the link capacity purchased from Intelsat would be greater than the actual capacity needed for the relay of one two-way voice circuit. Therefore, the excess capacity could be used for relaying data without incurring additional channel cost from the satellite portion of the communication link.

This memorandum is a sequel to Reference 1; it addresses, specifically, the use of the excess channel capacity that exists when a voice only channel is established as defined in Reference 1. The excess capacity would be used for the purpose of obtaining: (1) an up-data function on the up-link (ground station to satellite to manned spacecraft), and (2) a telemetry function on the down-link (manned spacecraft to satellite to ground station).

The salient points contained in Reference 1 are summarized in Sec. II to provide continuity and the excess capacity derived from Reference 1 is summarized in Sec. III. A discussion of performance criteria and modulation methods is given in Sec. IV for the combined voice and data functions. The determination of link capacities and system requirements is derived in Sec. V. Section VI provides a cost comparison of using the direct relay method via Intelsat satellites and the present cost of using Intelsat II which is providing point-to-point service between six Apollo MSFN land and ship stations and the Continental United States. The conclusions are given in Section VII. The cost model used in Reference 1 is included here as Appendix A, this is repeated because its understanding is essential to the discussion presented in this memorandum.

II. SUMMARY OF PREVIOUS WORK

The primary purpose of Reference 1, entitled "The Use of Intelsat Satellites for Direct Voice Communications with Manned Space Vehicles", was to examine the practicability of using present and anticipated Intelsat satellites for direct voice communications relay between an orbiting manned spacecraft and a ground station for the post-Apollo period. The major factors considered in Ref. 1 are: (1) types of Intelsat satellites and their utilization, (2) CCIR interference limits, (3) voice processing and modulation techniques, (4) implementation of the manned spacecraft terminal, and (5) satellite operation and cost model. The salient points of these subjects are summarized separately in this section. One overall desire in the formulation of Reference 1 was to arrive at a simple and "state of the art" type of system; therefore, many of these subjects were not treated exhaustively and the resulting systems are not claimed to be the most efficient possible. However, the tools provided in Reference 1 are sufficiently flexible and complete so that they can be used for additional extension. In fact, this memorandum is such an extension.

Types of Intelsat Satellites and Their Utilization

Four types of Intelsat satellites have been considered, the Intelsat II, III, III 1/2, and IV. For Intelsat IV, two different operations were possible for the down-link as it will be equipped with both an earth coverage antenna and a spot coverage antenna. All satellite repeaters were treated as linear amplifiers with constant gain, and the relay link equations were derived on that basis.

General relay link equations were derived for the up and down-links, and specific numerical equations were also given for each of the Intelsat satellites. The parameters of the Intelsat satellites and Intelsat ground stations were taken from published reports, documents, and articles authored by Intelsat or Comsat personnel. Each numerical equation was also presented as a set of parametric curves for quick reference. A particular functional variable chosen for the link equations is C/N_0, the carrier-to-noise power density ratio. This is a useful and convenient parameter as any communication requirement (voice, data, television) can be quickly expressed in these terms regardless of its form (analog or digital), its modulation method, (AM, FM, PM, PSK, multilevel, M'ary, etc.), or its use or non-use of coding. Therefore, Reference 1 can be used to size system parameters of these relay links for any desired communications function (or combination of functions), not just voice alone.

CCIR Interference Limit

The RF frequency bands presently used by Intelsat satellites are the same as those used by common carriers for microwave radio-relay systems on earth. In order to allow frequency sharing of these systems, various criteria to prevent mutual interference have been established by the International Radio Consultative Committee (CCIR) of the International Telecommunication Union. In Reference 1, we were particularly interested in possible interference in the downward direction, that is the emissions from Intelsat satellites and manned spacecraft interfering with terrestrial systems. Using the interference criterion established by CCIR, the maximum allowable effective isotropic radiated power density (EIRP/Hz) from the satellite and the manned spacecraft were derived as follows:

from Intelsat satellite	-24.6 dBW/Hz
from manned spacecraft	-49 dBW/Hz*

It was found that emission from Intelsat satellites can be maintained within the interference limit for the system considered, but the emission from the manned spacecraft would exceed its interference limit unless some interference avoidance technique was used. A combination of two techniques was proposed:

1. Apply operational constraints so that only the low level side-lobe of the RF emission from the manned spacecraft illuminates the Earth at any time.

2. Spread the RF spectrum intentionally for the down-link by some modulation or coding technique.

These can be achieved simply, although they may not be technically efficient, by (1) using a narrow beamwidth antenna on the manned spacecraft (1° and 2° at 6GHz beamwidths were assumed), these beamwidths correspond to 11 ft and 5.5 ft diameter parabolic antenna, and (2) pseudo-noise (PN) code modulation for digitized voice transmission.

Voice Processing and Modulation Techniques

Of all known voice processing and modulation techniques, the channel vocoder appears to be the most efficient, in terms of the C/N_0 requirement. However, the use of a vocoder does have

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*This number is sensitive to the manned spacecraft orbit, the number provided is based on a 260 nm circular orbit.

some disadvantages, namely, the size and weight of the equipment, the loss of some amount of naturalness in the processed voice signal, and the requirement for a high quality microphone with good low frequency response (70 Hz and lower). Although the use of vocoder was proposed for both up- and down-link transmissions, other conventional and simpler voice modulation methods were also suggested. It was concluded that frequency modulation with the use of threshold extension receiver can be used for the up-link (in particular, the frequency modulation with frequency feed back receiver, FMFB) and digital voice 30 kbps, using PCM/PM technique can be used for the down-link.

Implementation of Manned Spacecraft Terminal

The three major subsystems on the manned spacecraft were assumed to be as follows:

1. Antenna - as previously discussed, the sizes of the antenna assumed were 11 ft and 5.5 ft in diameter. In addition, the antenna was assumed to have an automatic pointing capability.

2. Transmitter - maximum power output of the transmitter was sized to be 100 watt.

3. Receiver - a receiving system temperature of 1800°K was assumed, the noise figure of the receiver itself was assumed to be 6 dB.

Satellite Operation and Cost Estimate

It was assumed that the manned spacecraft will be treated as a distinct and independent terminal similar to those used with Comsat for the links between the Intelsat II's and the Apollo ships (Vanguard, Redstone, and Mercury). It was further assumed that, as an independent terminal, (1) a fixed carrier frequency with a given bandwidth would be assigned to the terminal (frequency division multiplex), and (2) the bandwidth would be assigned from a limited number of bandwidth groups; each group representing a fixed number of hertz, therefore, there is a minimum bandwidth which must be purchased by the independent terminal user (5 MHz). This last criterion is the one that results in the creation of the "excess capacity" discussed in this memorandum.

The cost of utilizing the Intelsat satellites is estimated not on dollar cost but rather the number of equivalent voice channels required. The assumptions and procedures used for making the cost estimates are taken from Reference 1, Appendix D, and are presented here as Appendix A. Two factors determine the equivalent voice channel requirement, the bandwidth occupancy and the amount of EIRP needed from the Intelsat satellite. The final cost estimates were made by combining these two factors and using the procedures outlined in Appendix A.

III. SUMMARY OF EXCESS CAPACITY

The cost of using different types of Intelsat satellites to relay a two-way voice circuit between an orbiting manned spacecraft and a ground station was estimated in Reference 1. It was clear that in most cases the cost, or the capacity of the Intelsat satellites purchased, is larger than the capacity needed from technical considerations. This excess capacity could then be used for other communications functions at no extra cost. The extra cost refers to the space segment cost or the channel cost of using the Intelsat satellite. Additional cost will be incurred at the terminal because of increments in the terminal equipment.

The cost summary for the relay of a two-way voice circuit using various Intelsat satellites is taken from Reference 1, and presented here as Table 1. The use of Intelsat II, and Intelsat III 1/2 satellites will no longer be considered in this memorandum for the following reasons:

1. The use of Intelsat II is already marginal for two-way voice because it requires the use of a large amount of RF power (100 watts) and a large antenna (11 ft) on the manned spacecraft.

2. The Intelsat III 1/2 satellite program is not active at the present time.

Consequently, we are considering the use of Intelsat III and Intelsat IV satellites only. Two Intelsat III's are in operation over the Atlantic and Pacific Oceans. The Intelsat IV satellites are being procured with Hughes Aircraft Co. as the prime contractor.

A summary of the excess capacity that exists when using these satellites for a two-way voice circuit is presented in Table II. In the table, the excess capacities are separated into the RF bandwidth and the satellite EIRP ($EIRP_{IS}$). For all practical purposes, the bandwidth utilization is dictated by the down-link requirement, and the $EIRP_{IS}$ is

Voice Modes	Manned Spacecraft Antenna Size	Intelsat II		Intelsat III		Intelsat III 1/2		Intelsat IV Earth Coverage		Intelsat IV Spot Coverage	
		Channel Cost	SC RF Power	Channel Cost	SC RF Power	Channel Cost	SC RF Power	Channel Cost	SC RF Power	Channel Cost	SC RF Power
Vocoder both Links	11 ft	132	100 w	60	1.4 w	24	2.3 w	24	2.4 w	48	0.6 w
	5.5 ft*	--	--	156	9.1	60	16	24	14	48	3.3
FMFB Up-Link, Vocoder Down-Link	11 ft	264	100 w	156	1.4	60	2.3	24	2.4	48	0.6
	5.5 ft	--	--	588	9.1	192	16	60	14	84	3.3
Vocoder Up-Link, Digital Down-Link	11 ft	--	--	60	20	24	32	24	35	48	8
	5.5 ft	--	--	--	--	--	--	--	--	48	47
FMFB Up-Link, Digital Down-Link	11 ft	--	--	156	20	60	32	24	35	48	8
	5.5 ft	--	--	--	--	--	--	--	--	84	47

Table I - Cost Summary for Two-Way Voice Relay Using Intelsat Satellites

Channel Cost is in Equivalent Voice Channel Units

SC RF POWER is the RF transmitter power required from manned spacecraft, including an added margin of 3 dB.

*The data is presented, although vocoder up-link does exceed CCIR interference limit by 0.5 dB.

Table II: SUMMARY OF EXCESS CAPABILITY - Utilization of Intelsat Satellites For Two-Way Voice Relay Links

Voice Mode	Manned S/C Antenna Diameter	Intelsat III		Intelsat IV Earth Coverage Antenna		Intelsat IV* Spot Coverage Antenna	
		% $EIRP_{IS}$	% Bandwidth	% $EIRP_{IS}$	% Bandwidth	% $EIRP_{IS}$	% Bandwidth
Vocoder Both Links	5.5 ft	3	98	47	88	47	> 99
						> 99	97
	11 ft	36	> 99	86	98	86	> 99
						> 99	> 99
FMFB-Up-Link, Vocoder-Down-link	5.5 ft	2	> 99	20	94	20	> 99
						> 99	97
	11 ft	8	> 99	50	97	50	> 99
						> 99	> 99
Vocoder-Up-Link, Digital-Down-link	5.5 ft	--	--	--	--	47	> 99
						> 99	64
	11 ft	36	92	86	72	86	> 99
						> 99	93
FMFB-Up-Link, Digital-Down-Link	5.5 ft	--	--	--	--	20	> 99
						> 99	64
	11 ft	8	96	50	72	50	> 99
						> 99	93

*The split rows under Intelsat IV - Spot Coverage Antenna come about because separate repeaters are used for up and down links, while a single repeater is used for the other cases. The upper split row refers to the up-link, and the lower to down-link.

dictated by the up-link requirement. Therefore, the excess bandwidth capacity can be used for sending telemetry from the manned spacecraft, and the excess $EIRP_{IS}$ capacity can be used for sending up-data to the manned spacecraft.

IV. PERFORMANCE CRITERIA AND MODULATION METHODS

Three types of voice processing and modulation methods were presented in Reference 1 and are shown in Table III:

Table III - Performance Criteria for Various Voice Modulation Method

Voice Modulation	S/N_{req}	Bandwidth	$C/N_{O_{req}}$
Vocoder, 2.4 kbps, PCM/PM	7 dB	3200 Hz	42 dB-Hz
Digital voice, 30 kbps, PCM/PM	8 dB	36 kHz	53.6 dB-Hz
FM with threshold extension receiver, m = 2	5.2 dB	18 kHz	47.8 dB-Hz

S/N_{req} = Signal-to-noise power ratio required in corresponding noise

BW = RF noise bandwidth.

$C/N_{O_{req}}$ = RF power-to-noise power spectral density ratio required = S/N_{req} x BW.

m = FM modulation index

It was suggested that FM voice is only suitable for the up-link, digital voice is only suitable for the down-link, and vocoder voice can be used for either of the links. A quick glance at Table II indicates that whenever FM voice is used, very little excess $EIRP_{IS}$ capability is left for possible simultaneous up-data transmission. This problem is further compounded by the multiplexing requirement of combining an analog signal (FM voice) and a digital signal (up-data). For instance, the use of the familiar Apollo USB system, which is a phase modulated system with frequency division multiplex, would result in an RF power penalty of approximately 6 dB because of modulation loss.[(2)*] It becomes apparent that the use of such a method is unacceptable as the excess $EIRP_{IS}$ capability is insufficient to cover the modulation loss. Consequently, the use of FM voice is not considered further for simultaneous voice and up-data transmission on the up-link.

The use of a vocoder requires specialized equipment which is relatively heavy and bulky; therefore, it may not be acceptable for manned spaceflight usage. A possible alternate voice processing method is the use of an infinitely clipped digitized speech with one bit encoding per speech sample. The quality of the speech depends on the sampling rate, a sampling rate of 7200 samples per second, which results in a 7.2 kbps digitized speech signal, would provide a very good quality (better than 90% word intelligibility)[(3)] voice link. However, if the acoustical background noise were high, this technique would probably yield poor results. Since this technique is suggested for the up-link, we are assuming that the acoustical environment at the control center can be satisfactorily controlled.

The performance criteria for the up-link are summarized in Table IV. One notable item from Table IV is that, whenever several signals of different performance requirements are combined by using a simple serialized time division multiplex (TDM) system, the S/N_{req} of the multiplexed signal is dictated by the signal with the highest performance requirement. In this case, the up-data function which requires (or assumed to require) 10^{-6} bit error rate (BER). Obviously, this results in an inefficient system (see items 4 and 5 in Table IV). A better system design would strive to equalize the performance requirements of all functions, that is, the BER of the transmitted bits. Since the communication channel being considered is not bandwidth limited, the up-data signal can be coded so that its S/N_{req} would be reduced to the same value as that of the voice signal (6.8 dB) at the expense of RF bandwidth. Since the subject of coding technique and its optimal use is beyond the scope of this memorandum, it will not be treated in detail here. There is a simple way to equalize the two functional

*Reference 2 also contains the relative performance advantages of several modulation methods including those discussed here.

Up-Link Function	S/N_{req}	Bit Rate	$C/N_{0\,req}$*
1. Vocoder (10^{-3}BER)	6.8 dB	2400 bps	45.6 dB-Hz
2. Infinitely clipped digitized voice (10^{-3}BER)	6.8 dB	7200 bps	50.5 dB-Hz
3. Up-Data (10^{-6}BER)	10.7 dB	1000 bps	45.7 dB-Hz
4. Vocoder plus Up-data (10^{-6}BER)	10.7 dB	3400 bps	51 dB-Hz
5. Infinitely clipped digitized voice plus Up-Data (10^{-6}BER)	10.7 dB	8200 bps	54.8 dB-Hz
6. Vocoder (10^{-3}BER) plus Up-Data (10^{-6}BER)**	7.7 dB	4400 bps	49.2 dB-Hz
7. Infinitely clipped digitized voice (10^{-3}BER) plus Up-Data (10^{-6}BER)**	7.7 dB	9200 bps	52.4 dB-Hz

S/N_{req} = Signal-to-noise ratio required in bit rate bandwidth

$C/N_{0\,req}$ = RF power-to-noise spectral density ratio required

= S/N_{req} x bit rate bandwidth x margin

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*Includes 2 dB margin for inperfect demodulator and 3 dB additional margin.

**A redundant bit is sent for every signal bit of the up-data signal.

Table IV - Performance Criteria for Up-Link Communications Functions requirements in this case; a redundant bit could be transmitted for every up-data signal bit. During the demodulation process, the integration time for every signal bit is lengthened to include two transmitted bit periods. The net result is to reduce the energy of every transmitted bit to one half of that required in the signal bit without sacrificing the performance. The net advantage of using this method can be seen by comparing items 4 and 5 with 6 and 7 in Table IV. It should be pointed out that the 1.0 kbps up-data signal used for Apollo, which can be assumed here, is already a coded signal. Depending on the content of the message, different coding techniques are used. A detailed discussion of this system can be found in Reference 4 and 5. In general, one may conclude that the Apollo up-data system can be reformated for future use so that the transmitted bit error rate can be relaxed without sacrificing the requirements on message rejection rate and the probability of undetected error.

For the down-link, the excess bandwidth capacity will be utilized for sending telemetry (TLM), operational and/or scientific information. The TLM information will be combined with the digitized voice signal using a TDM method. The performance requirement for the TLM is assumed to be a BER of 10^{-4} which also is the performance requirement of the multiplexed signal. Assuming a non-ideal demodulator and allowing a 3 dB margin, the S/N_{req} for the multiplexed signal is 13.3 dB in bit rate bandwidth

V. LINK CAPABILITIES AND SYSTEM REQUIREMENTS

The methods for determining the RF performance of relayed links has been established in Reference 1; the same numerical equations and graphs apply here. From these tools, we are seeking the answers to the following questions:

1. Up-link:

   a. Can the up-link support voice and up-data signals simultaneously without increasing the channel cost (the space segment) from that necessary to support voice transmission alone

   b. Which Intelsat satellite can do the job?

   c. Can we stay within the CCIR interference criterion without the use of spread-spectrum techniques*

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*See Reference 1 for discussion on CCIR interference limit and spread spectrum techniques.

d. What size antenna do we need on the manned spacecraft?

2. Down-link:

a. Can the down-link support voice and telemetry signals simultaneously without increasing the channel cost (the space segment) from that necessary to support the voice transmission alone?

b. What is the relationship between the transmitter power required on the manned spacecraft and the transmission rate of the telemetry data for various Intelsat satellites?

c. Can we stay within the CCIR interference criterion without the use of spread spectrum techniques?

Figures 1 and 2 provide answers to the first set of questions. Figure 1 assumes that a vocoder is used for the voice transmission, and Figure 2 assumes that infinitely clipped digitized voice is used for the voice transmission. The solid points on the figures represent the channel capacity purchased from Intelsat III and Intelsat IV in terms of EIRP for the purpose of two-way voice transmission. The corresponding channel capacity in terms of C/N_0 follows the log-log linear relationship as shown for two different receiving antenna sizes on the manned spacecraft (11 ft and 5.5 ft diameter parabolic antennas). From Figures 1 and 2, it can be seen that simultaneous voice and 1.0 kbps up-data signals can be transmitted simultaneously on the up-link at no additional cost under the following conditions:

1. using Intelsat IV satellites,

2. vocoder voice ban be multiplexed with the up-data signal without the need of any additional coding on the up-data signal,

3. infinitely clipped digitized voice can be multiplexed with the up-data signal only when the up-data signal has additional coding,

4. the minimum antenna size required on the manned spacecraft is approximately equivalent to a 6.5 ft diameter parabolic antenna (vocoder plus coded up-data), and

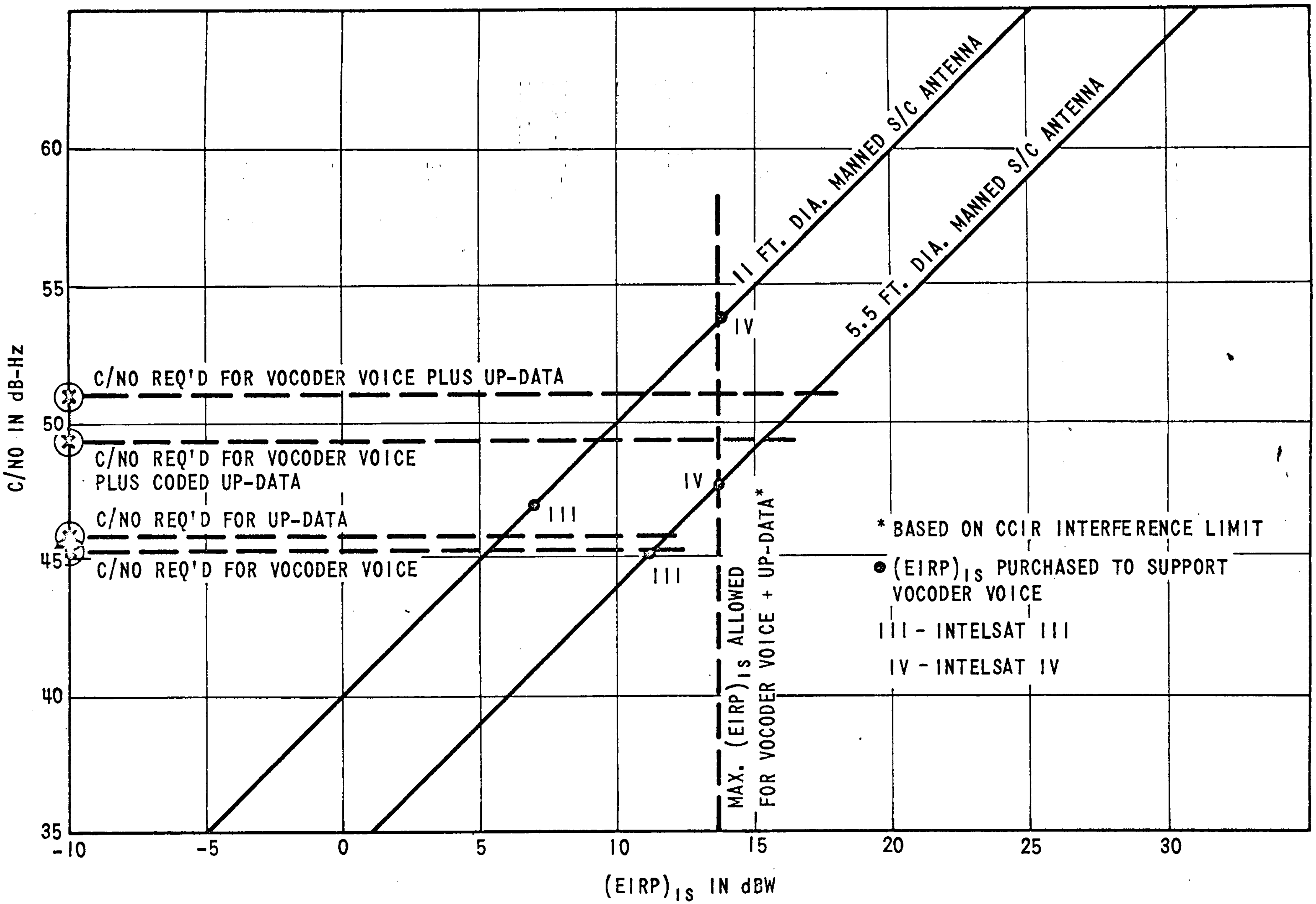

FIGURE 1 - INTELSAT UTILIZATION REQUIREMENTS - UPLINK
FOR VOCODER VOICE PLUS UP-DATA
MANNED SPACECRAFT T_{SYST} = 1800°K

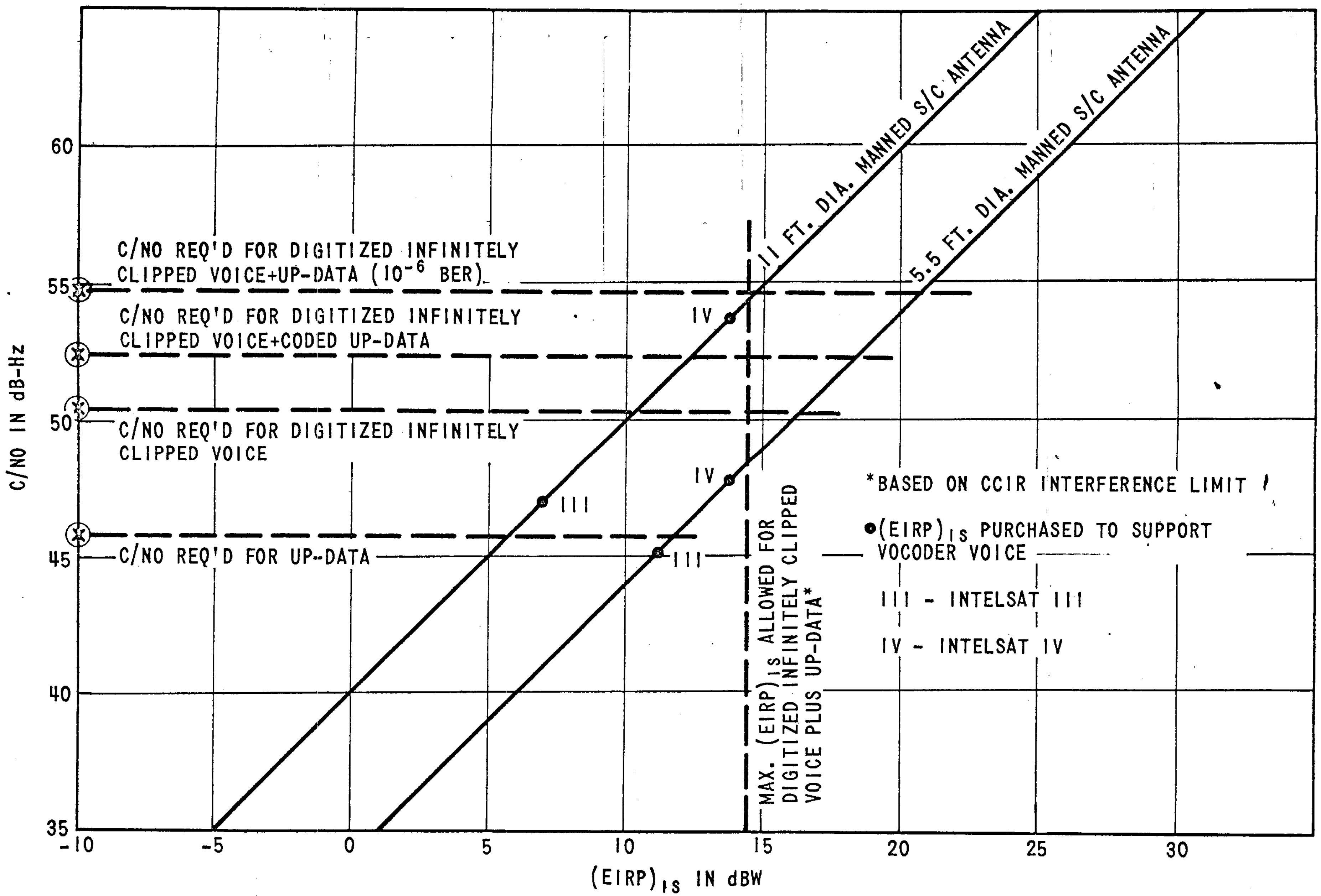

FIGURE 2 - INTELSAT UTILIZATION REQUIREMENTS - UP-LINK FOR DIGITIZED INFINITELY CLIPPED VOICE+UP-DATA MANNED SPACECRAFT T_{SYST} = 1800° K

5. the multiplexed up-link can be operated within the CCIR interference limit without the use of spread spectrum technique.

Figures 3 to 8 provide answers to the second set of questions concerning the down-link. The down-link capacities in terms of telemetry data transmitting rate as a function of the required transmitter power on the manned spacecraft are presented in Figures 6-8. These figures also include the following functional variables:

1. The type of satellites - Intelsat III and IV.

2. The type of satellite antenna used on Intelsat IV for the down-link - earth coverage or spot coverage antennas.

3. The size of antenna used on the manned spacecraft - 11 ft or 5.5 ft diameter parabolic antennas.

4. The type of voice processing used - vocoder and digitized (30 kbps) voice.

Figures 3 to 5 present the performance of the various down-link combinations. The oblique and vertical lines in these figures represent the CCIR interference limit and the purchased bandwidth limits, respectively. Each set of oblique and vertical lines define the bounds of the permissible operating region of the relayed link. The intersection of the two lines represents maximum utilization, in terms of RF bandwidth, of the relayed link and also the maximum data rate available. For the most efficient utilization, in terms of RF power, the operating point should fall on the oblique line, which represents the CCIR interference limits. Figures 6 to 8 are derived from the points on these lines.

Selected points from Figures 6 to 8 are tabulated in Table V. The chosen points are (1) manned spacecraft transmitter power of 20 watts, (2) manned spacecraft transmitter power of 100 watts, and (3) 100% utilization of the purchased bandwidth of the Intelsat satellite. These points are selected because a 20 watt transmitter is obtainable at the present time, a 100 watt transmitter is considered to be obtainable in the near term (3 years), and the last point represents the upper bound of the excess channel capacity available for the down-link.

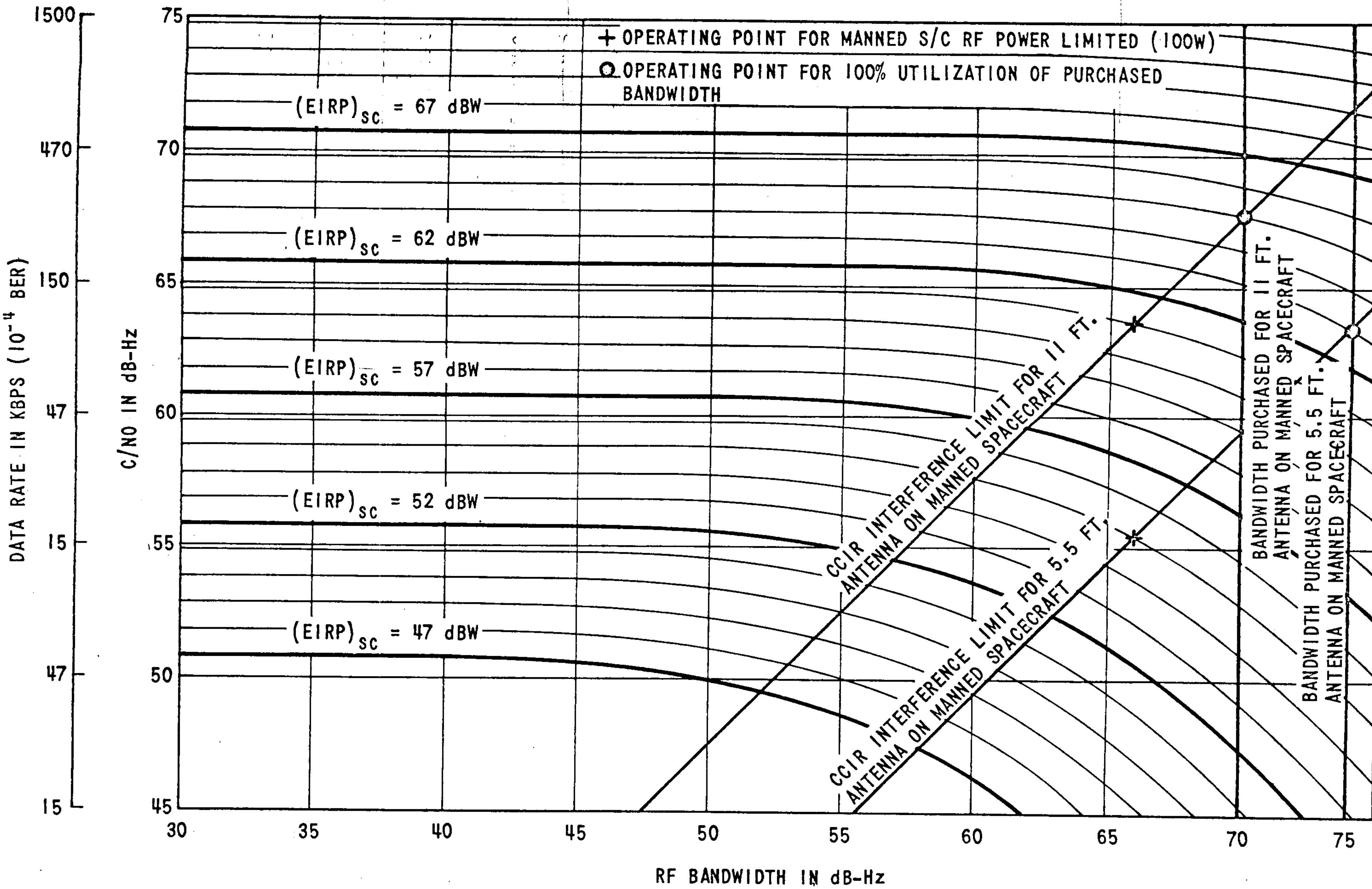

FIGURE 3 - INTELSAT III BANDWIDTH UTILIZATION - SPACECRAFT TO GROUND LINK

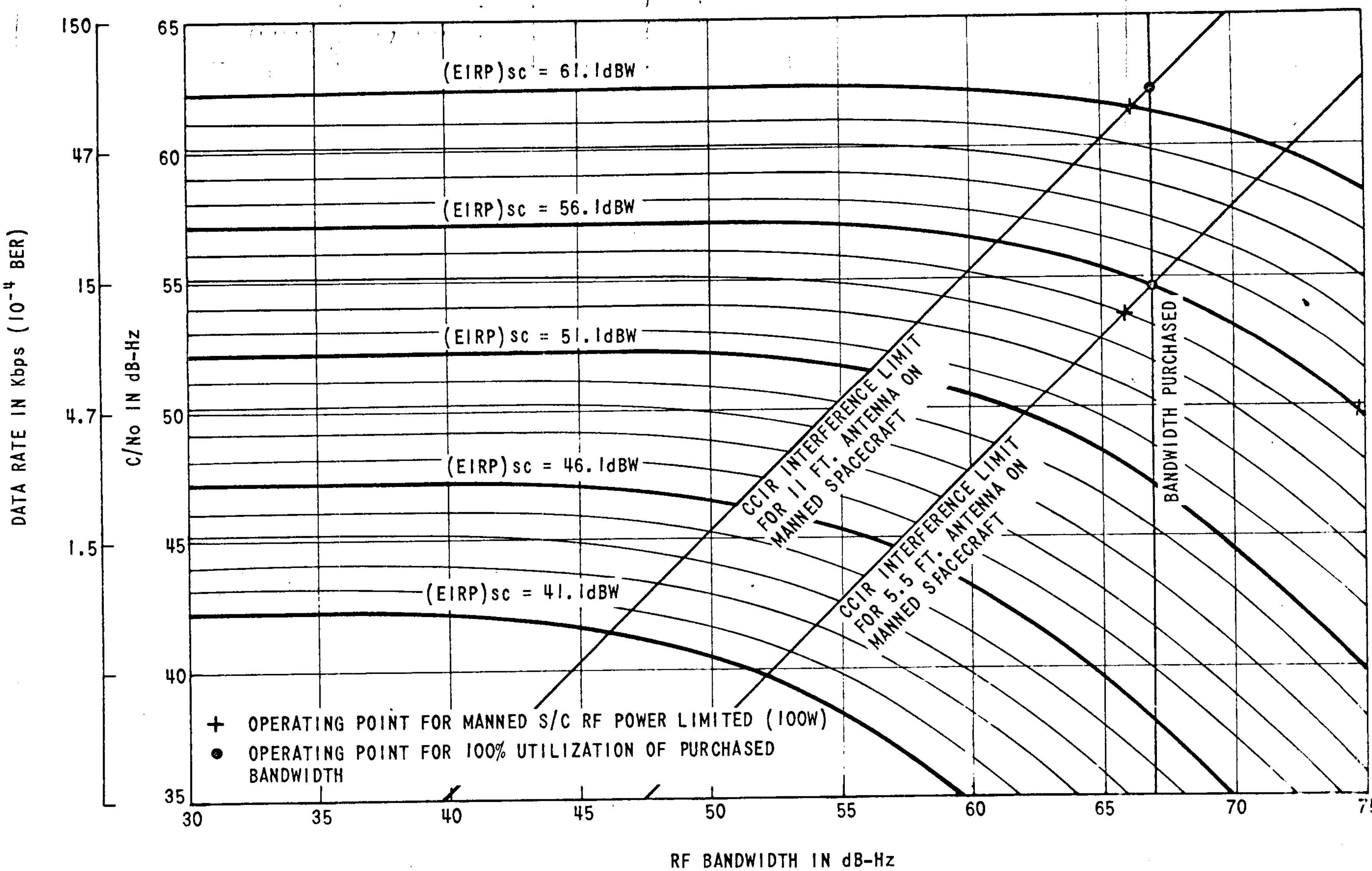

FIGURE 4 - INTELSAT IV UTILIZATION REQUIREMENT. SPACECRAFT TO GROUND LINK USING EARTH COVERAGE ANTENNA

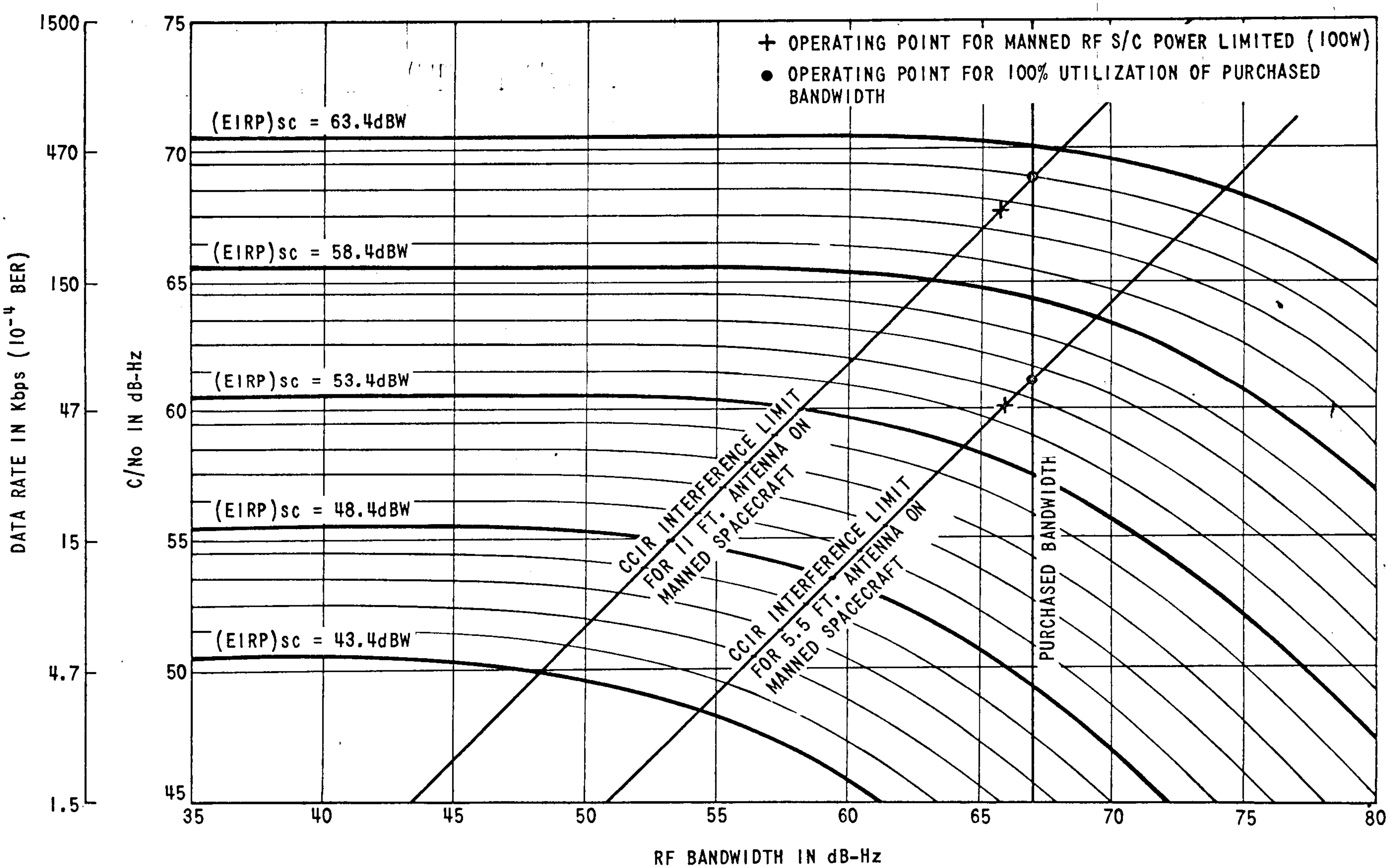

FIGURE 5 - INTELSAT IV UTILIZATION-SPACECRAFT TO GROUND LINK USING SPOT COVERAGE ANTENNA ON INTELSAT IV

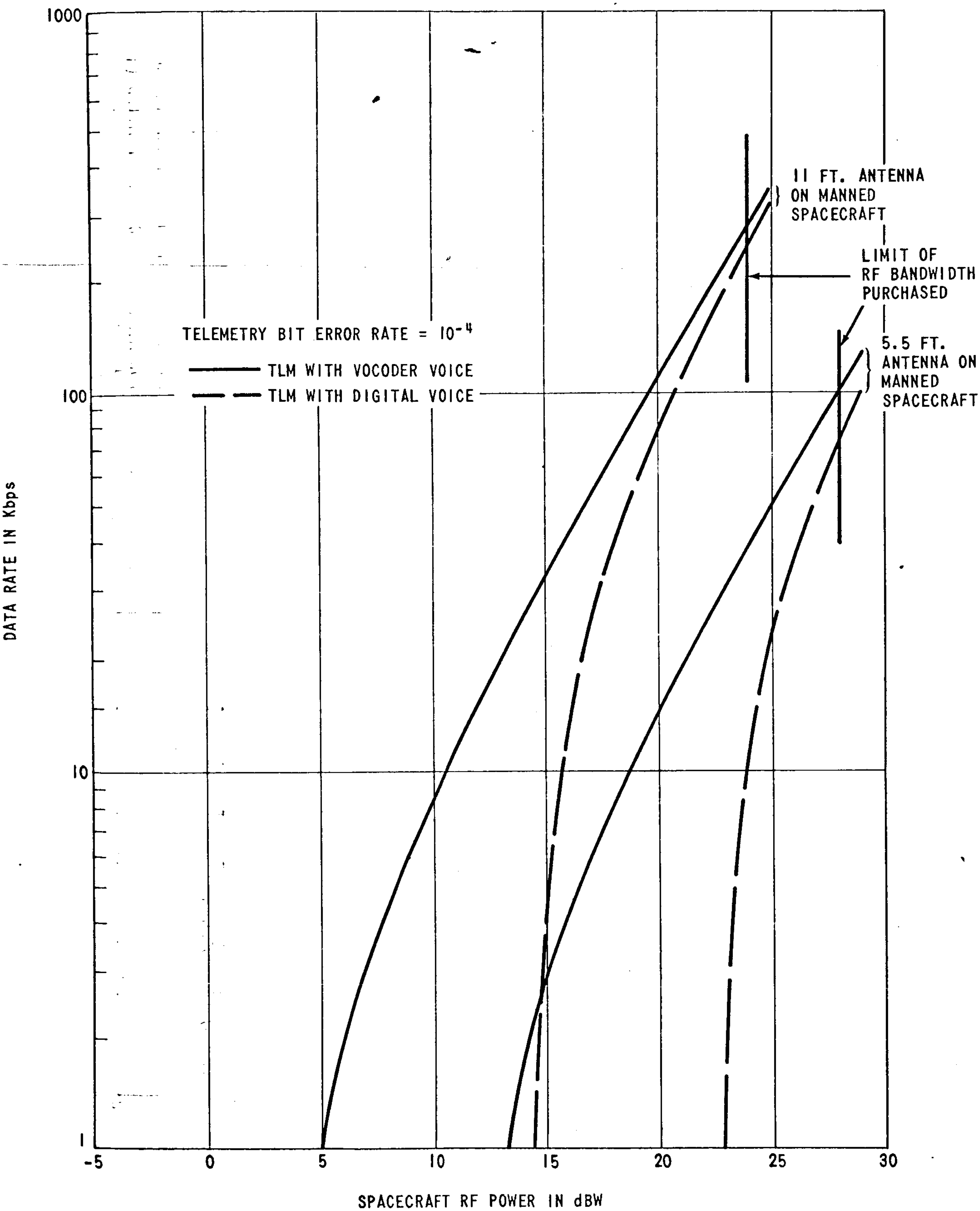

FIGURE 6 - TELEMETRY DATA RATE vs. MANNED SPACECRAFT RF POWER REQUIRED
MANNED SPACECRAFT TO GROUND LINK USING INTELSAT III

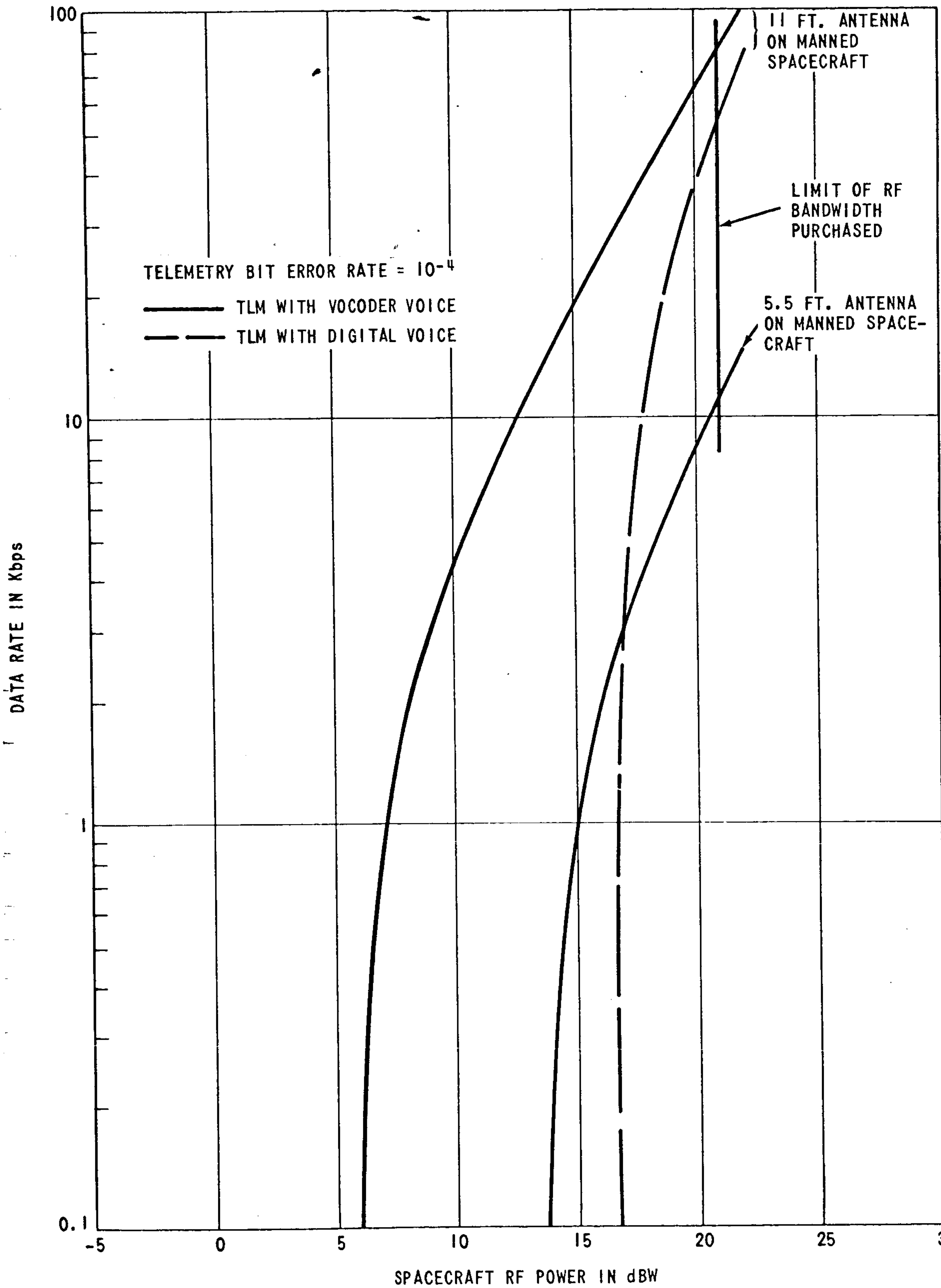

FIGURE 7 - TELEMETRY DATA RATE vs. MANNED SPACECRAFT RF POWER REQUIRED MANNED SPACECRAFT TO GROUND LINK USING INTELSAT IV EARTH COVERAGE ANTENNA

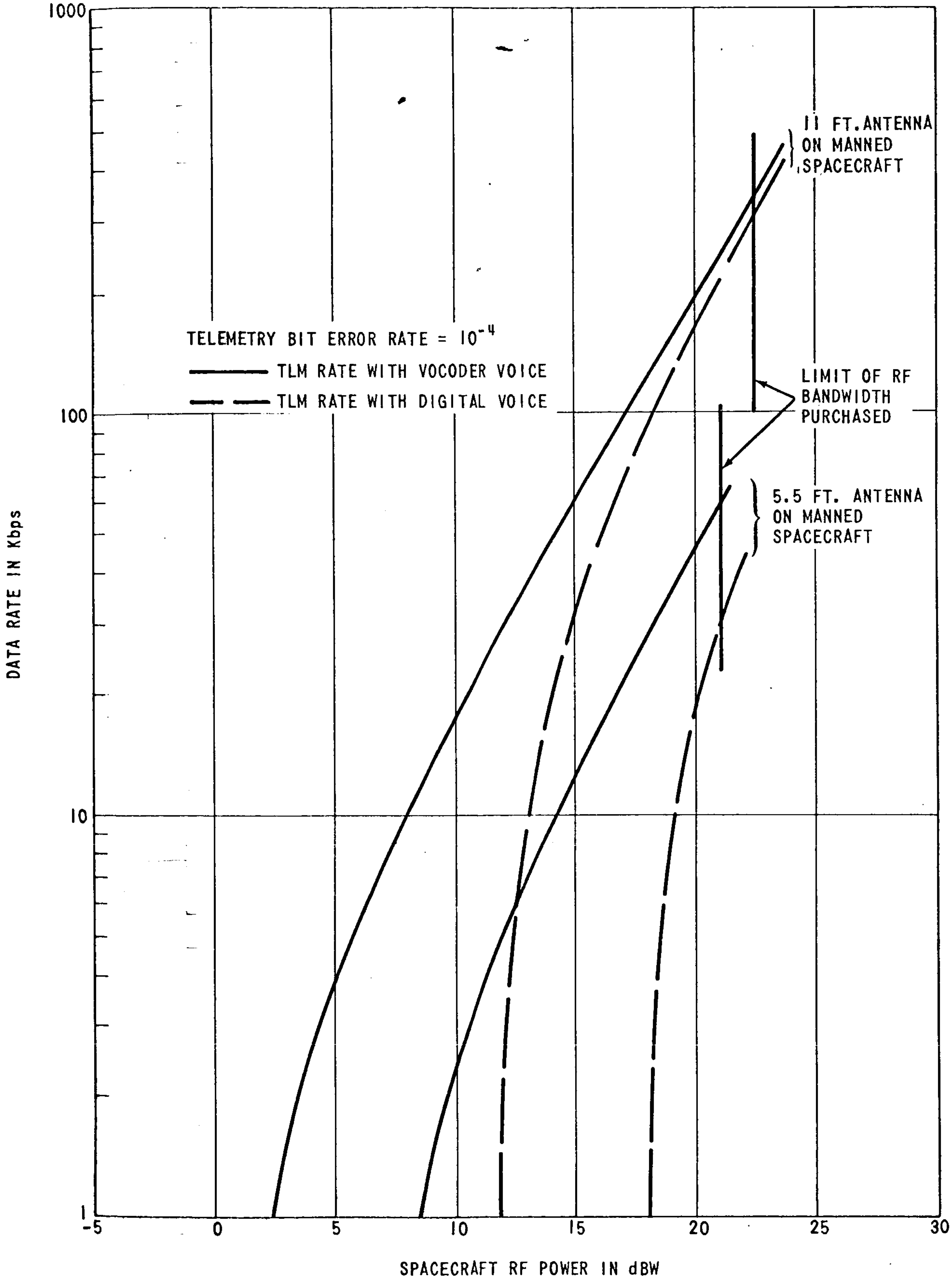

FIGURE 8 - TELEMETRY DATA RATE vs. MANNED SPACECRAFT RF POWER REQUIRED MANNED SPACECRAFT TO GROUND LINK USING INTELSAT IV SPOT COVERAGE ANTENNA

Intelsat Satellite	Manned S/C Antenna Size	Manned S/C P_t=20w		Manned S/C P_t=100w		100% BW Utilization	
		Vocoder Voice + TLM	Digital Voice + TLM	Vocoder Voice + TLM	Digital Voice + TLM	Vocoder Voice + TLM	Digital Voice + TLM
III	11 ft	20 kbps	requires 20w to support voice alone	100 kbps	80 kbps	270 kbps	240 kbps
	5.5 ft	0.9 kbps	requires 100w+ to support voice alone	14 kbps	--	100 kbps	70 kbps
IV Earth Coverage Antenna	11 ft	11 kbps	requires 35w to support voice alone	60 kbps	35 kbps	80 kbps	50 kbps
	5.5 ft	0	requires 100w+ to support voice alone	8.4 kbps	--	11 kbps	--
IV Spot Coverage Antenna	11 ft	35 kbps	10 kbps	190 kbps	160 kbps	340 kbps	310 kbps
	5.5 ft	7 kbps	requires 47w to support voice alone	45 kbps	17 kbps	60 kbps	30 kbps

Table V - Telemetry Data Rate of the Multiplexed Signal for the Down-Link

VI. COST COMPARISON

A complete cost analysis on the effectiveness of using Intelsat satellites as a direct relay for voice and data transmission between an orbiting manned spacecraft and a ground station would involve many factors. Some of the major ones are:

1. cost of using Intelsat satellites,
2. cost of transferring information from Intelsat ground station to MCC-H (NASCOM),
3. cost of implementing a compatible terminal on the manned spacecraft,
4. cost savings resulting from a reduction of the number of stations of the present MSFN,
5. cost savings from reducing the present NASCOM configuration,
6. increase in operational effectiveness of manned space flight missions,
7. comparison of real time information transfer capability, and
8. circuit reliability.

Since some of these factors require extensive analysis, a complete cost analysis is not presented in this section. Instead, we would like to touch on two areas which we believe to be both interesting and illuminating; these are:

1. A comparison of the present cost of using Intelsat II for point-to-point service (between six MSFN land stations and ships and U.S. for the support of Apollo missions) and the cost of using Intelsat III or IV for direct relay service.
2. A comparison of the real time information transfer capability in conjunction with (1) above.

The cost of using Intelsat II satellites in the present Apollo support configuration is extracted from Reference 6. Again, the unit of cost is expressed in terms of equivalent voice channel as it was in Reference 1. The EIRP utilization of the Intelsat II satellites for NASA services is as follows:

Pacific Region	
Pacific ship to Brewster Flat	1.37 W
Carnarvon to Brewster Flat	1.37 W
Brewster Flat to Carnarvon	1.37 W
Brewster Flat to Pacific Ship	5.81 W
Atlantic Region	
Atlantic Ship to Andover	1.37 W
Indian Ship to Andover	1.37 W
Ascension to Andover	1.37 W
Grand Canary to Andover	1.37 W
Andover to all	11.62 W
Total	27.02 W

The total of 27 W should be revised as follows:

1. substract 2.74 W because only two out of the four terminals in the Atlantic Region are being supported at a time, and

2. subtract 4.64 W because of the recent ground station improvements at the Brewster Flat and Andover stations. The improvements involve the increase in antenna size from 42 ft to 85 ft diameter and the reduction of ground receiving system noise temperature. These changes resulted in a net gain in performance of 6.5.

The revised total is, therefore, 19.64 W or approximately, 20W. Two Intelsat satellites are used for the service, each satellite is capable of radiating 25 W of EIRP(7); the percentage of EIRP utilized by NASA is:

$$\frac{20}{2 \times 25} \times 100 = 40\%$$

Each Intelsat II satellite has a capacity of 480 equivalent voice channels; therefore, the cost to NASA is:

$$2 \times 480 \times 40\% = 384 \text{ equivalent voice channels.}$$

The actual cost to NASA computed in detail by Comsat Corp. can be found in Reference 8. From a more complicated set of formulas, the Comsat cost number is 337.2 equivalent voice channels. However, this does not represent the total cost to NASA as additional charges are made by the governments of the United Kingdom, Australia, and Spain for the use of their respective ground stations at Ascension Island, Carnarvon, and Grand Canary Islands. Therefore, the cost number of 384 equivalent voice channels arrived at by using the simplified approach can be used with good confidence for our purpose.

The service provided by the Intelsat II satellites is six duplex voice/data plus two teletype circuits between each of the six MSFN sites and the United States. However, the service provided between the manned spacecraft and MCC-H in real time is:

1. Manned spacecraft to MCC-H - voice plus four (4) data channels, each data channel has the capacity of 2.4 kbps, and

2. MCC-H to manned spacecraft - voice plus one (1) data channel, each data channel has the capacity of 2.4 kbps.

The remaining circuits are used for station coordination and spares. Moreover, the real time coverage is limited by the station coverage time which depends on the altitude and the inclination angle of the manned spacecraft orbit. For example, these six MSFN sites provided approximately 12% real time coverage of the Apollo 7 mission duration.

Similar service can be provided by Intelsat IV using its spot coverage antenna for a direct relay link; the cost estimated is:

Satellites Required	% Real Time Coverage	Cost
1	45	48 channels
2	90	96 channels
3	100	150 channels

the implementation needed on the manned spacecraft is as follows:

antenna	- 11 ft diameter parabolic dish
transmitter power	- 20 watts
receiving system temperature (including line losses)	- 1800°K
down-link voice	- 30 kbps digital
up-link voice processing	- infinitely clipped digital 7.2 kbps
up-link up-data coding	- simple one redundant bit for each signal bit
down-link spread spectrum technique	- PRN code (see Reference 1)

The cost of using three Intelsat satellites for 100% coverage is more than triple the cost of using a single satellite, because one of the three satellites would not be in view of a U. S. ground station. Therefore, additional allowance is needed to take care of the extra ground-to-ground relay (double hop).

VII. CONCLUSIONS

Table VI is a summary of the utilization of Intelsat satellites for direct relay service between a manned spacecraft and a ground station. From Table VI, one can obtain an estimate of the relayed link capacity using either Intelsat III or Intelsat IV satellites; in addition, the following major system parameters are also given:

1. manned spacecraft antenna size requirement,
2. manned spacecraft transmitter power requirement (P_t),
3. voice processing requirement, and
4. cost of using the satellite.

It is well to note that the link capacities established in this memorandum, and given in Table VI, are calculated from a fixed

TABLE VI: Summary of Utilization of Intelsat Satellites for Direct Relay Services

Intelsat Satellite Used	Manned S/C Antenna Size	Two-Way Simultaneous Direct Relay Service			Estimated Cost in Equivalent Voice Channels	
		Up-Link	Down-Link			
			Manned S/C P_t = 20 w	Manned S/C P_t = 100 w	Coverage	Cost
III	5.5 ft	Vocoder voice or 0.9 kbps data	Vocoder voice and 0.9 kbps data	Vocoder voice and 14 kbps data	45% 90% 100%	156 312 475
	11 ft	Vocoder voice or 1.3 kbps data	Vocoder voice and 20 kbps data, or digital voice or 30 kbps data	Vocoder voice and 100 kbps data, or digital voice and 80 kbps data	45% 90% 100%	60 120 188
IV Earth Coverage Antenna	5.5 ft	Vocoder voice or 1.6 kbps data	Vocoder voice or 1.6 kbps data	Vocoder voice and 8.4 kbps data	45% 90% 100%	24 48 80
	11 ft	Vocoder voice and 3.9 kbps data, or clipped voice and 1.3 kbps coded data	Vocoder voice and 11 kbps data	Vocoder voice and 60 kbps data, or digital voice and 35 kbps data	45% 90% 100%	24 48 80
IV Spot Coverage Antenna	5.5 ft	Vocoder voice or 1.6 kbps data	Vocoder voice and 7 kbps data	Vocoder voice and 45 kbps data, or digital voice and 17 kbps data	45% 90% 100%	48 96 150
	11 FT	Vocoder voice and 3.9 kbps data, or clipped voice and 1.3 kbps coded data	Vocoder voice and 35 kbps data, or digital voice and 10 kbps data	Vocoder voice and 190 kbps data, or digital voice and 160 kbps data	45% 90% 100%	48 96 150

Notes: Vocoder voice is a digitized voice using vocoder, bit rate is 2.4 kbps.
Digital voice is a straight forward digitized PCM voice, bit rate is 30 kbps.
Clipped voice is a digitized voice after a infinitely clipped processing, bit rate is 7.2 kbps.
The bit error rate for the up-link is 10^{-6}.
The bit error rate for the down-link is 10^{-4}.

channel cost represents that required for the direct relay of a two-way voice circuit given in Reference 1. It is obvious that the link capacity can be expanded by using a larger portion of the Intelsat satellite's capacity; but the channel cost of using the Intelsat satellite would also increase.

Several conclusions can be made from Table VI and the previous discussion:

1. Intelsat III cannot support a simultaneous voice and up-data for the up-link; these functions must be accomplished through operational procedure on a time shared basis.

2. An 11 ft antenna is needed on the manned spacecraft if simultaneous voice and up-data functions are required on the up-link using Intelsat IV.

3. If the use of a vocoder proved to be undesirable for space operation, the up-data signal needs to be coded in order to achieve a low bit error rate (10^{-6}).

4. In all cases, all digital modulation using PCM/PM and time division multiplexing techniques appears to be desirable.

5. With a properly equipped manned spacecraft terminal, it is cost effective to use an Intelsat IV satellite for direct relay service when compared with the present cost of using Intelsat II satellites for Apollo operations. For similar real time information flow, direct relay cost is about 80% less (80 channels vs. 384 channels), and the real time coverage time is increased to 100%.

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Attachments
Appendix
References

APPENDIX A**

Assumptions and Procedures of Cost Estimates for Utilizing Intelsat Satellites

The estimates of the cost of utilizing Intelsat satellites are based on several assumptions:

1. There is no cost differential among different types of Intelsat satellites at a given time.

2. The utilization of Intelsat satellites by manned space flight operations is a unique application, therefore, the orbiting manned spacecraft is treated as a distinct and independent user terminal.

3. Distinct carrier group assignments are dedicated to the two-way voice relay link for and during manned space flight operations.

4. The carrier groups assumed are those presently planned for Intelsat III as follows:*

   a. 5 MHz -- 24 equivalent voice channels

   b. 10 MHz -- 60 equivalent voice channels

   c. 20 MHz -- 132 equivalent voice channels

   d. any combinations of a, b, and c.

   The implication is that these are the integral carrier group and, therefore, represent the number of equivalent voice channels that must be purchased regardless of the actual RF bandwidth needed for a single two-way voice transmission by manned space flight operations.

5. Each equivalent voice channel represents a single unit cost in dollars regardless of their allocation in the carrier group assignment.

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*R. Stamminger, "Transmission System Planning for Intelsat III", Presented at AIAA Second Communication Satellite Systems Conference, April, 1968. AIAA Paper No. 68-448.

**From Reference 1, Appendix D.

Appendix A (Contd.)

Two criteria are used for estimating the cost, the RF bandwidth used and the Intelsat satellite EIRP used. Both parameters have been calculated in Reference 1, they are compared and determined as to which is the dominant parameter. For instance, for the up-link case very little bandwidth is needed but a large amount of satellite EIRP is used. The reverse is true for the down-link.

To translate the EIRP of the Intelsat satellite to equivalent voice channels, the following procedure is used:

1. Determine the required EIRP as a percentage of the total EIRP available from the Intelsat satellite. The available EIRP of the satellites are as follows:

Intelsat II	13.5 dBW
Intelsat III	23.0 dBW
Intelsat III 1/2	30.5 dBW
Intelsat IV	42.0 dBW

These numbers are those presented in Table I* less 2 dB. The 2 dB difference takes care of the "back-off" factor which is needed for avoiding excessive intermodulation distortion caused by the TWTA on the satellite operating near saturation under multiple carrier operations.

2. The number of equivalent voice channels needed is the product of percentage EIRP used and the total channel capacity of the satellite. The voice channel capacities of the various satellites are:

Intelsat II	480 equivalent voice channels
Intelsat III	2,400 equivalent voice channels
Intelsat III 1/2	3,800 equivalent voice channels
Intelsat IV	16,000 equivalent voice channels

3. The number of equivalent voice channels used (i.e., must be purchased) is the integral number of equivalent voice channels of a particular carrier group as indicated in 4a, b, c, and d as follows:

*Reference 1.

Appendix A (Contd.)

Number of Channels Needed	Number of Channels That Must be Leased
1 to 24	24
25 to 60	60
60 to 132	132
132 to 156	156
156 to 192	192
192 to 264	264

and so on.

The up- and down-links will be combined into one carrier group for all cases except when the down-down-link uses the spot coverage antenna of Intelsat IV. For the latter case, an individual carrier group has to be used for each link. The implication is that if the up-link cost is primarily due to satellite EIRP used and the down-link cost is primarily due to the satellite bandwidth used, then the combined cost is the larger of the two.

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